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Risk Factors, Prevention, and Recovery of Knee Joint Injuries in Marathon Runners

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Abstract

Driven by the national strategies of "Fitness for All" and "Building a Strong Sports Nation," marathon running has experienced rapid growth in China, with a significant increase in participants. However, due to the high-load nature of marathon running, knee injuries have become a common health risk among runners, severely affecting their performance and overall health. Despite this, domestic research has yet to establish a systematic understanding of the risk factors, prevention, and recovery strategies for knee injuries in marathon runners. Given the extensive research on marathon-related knee injuries abroad, this study aims to review and synthesize international research on the risk factors, prevention, and recovery strategies for knee injuries in marathon runners. In terms of risk factors, the primary internal factors for knee injuries include muscle strength and running technique, while external factors encompass excessive training load and footwear type. Effective prevention strategies include balancing muscle strength, optimizing running technique, managing training load, and selecting appropriate running shoes. For injured runners, initial recovery strategies involve physical therapy, medication, and exercise therapy. In the intermediate phase, gradual load increase and progress monitoring are essential, followed by a step-by-step return to running to ensure a scientifically guided recovery. This study provides marathon runners with a systematic approach to the prevention and management of knee injuries, aiming to support their long-term healthy running careers.

Keywords

Marathon running; Knee joint injury; Risk factors; Prevention strategies; Recovery strategies.

1. Introduction

Under the "Fitness for All" and "Building a Strong Sports Nation" strategies, marathon events have seen significant development, with a continuous increase in participants, sparking a "marathon craze" in China. Data indicates that between 2014 and 2019, the number of road races nationwide grew from 54 to 1,828, with over 7 million participants. In 2023 alone, 699 road races (excluding trail running and mountain events) were held nationwide, with marathons accounting for 88.98% and a total participation of 6.0519 million[1]. Due to the characteristic of enduring high training loads over long periods, runners are prone to sports injuries. Research on the anatomical distribution of marathon-related injuries identifies the knee as the most common injury site, accounting for 28% of injuries, compared to 26% for the ankle/foot and 16% for the lower leg[2]. Knee joint injuries in marathon runners significantly impact their competitive performance and physical health. Therefore, identifying risk factors and developing effective prevention and recovery strategies are beneficial for maintaining runners' performance and well-being. Currently, domestic research on knee injuries in

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marathon runners focuses on biomechanical characteristics[3,4], imaging diagnosis and predictive applications[5-7], and analysis of injury status and influencing factors[8-12]. While domestic scholars have explored risk factors for marathon-related knee injuries to some extent, certain potential factors, such as running technique and footwear type, have been relatively overlooked. Furthermore, a systematic body of research on effective prevention and recovery strategies for these injuries has not yet been established in China. Given the substantial body of research on marathon-related knee injuries internationally, this study aims to review and synthesize foreign research on the risk factors, prevention, and recovery strategies for knee injuries in marathon runners.

2. Risk Factors for Knee Injuries in Marathon Runners

During a long-distance marathon, runners' knees are subjected to prolonged stress and repetitive loading, the accumulation of which can often lead to various injuries. The occurrence of knee injuries in marathons is typically the result of multiple interacting internal and external factors. For instance, factors such as muscle strength, running technique, training load, and footwear type all influence knee health. A deeper understanding of these risk factors, particularly those that are modifiable, can better guide runners in adopting preventive measures to reduce the incidence of knee injuries.

2.1. Internal Risk Factors

2.1.1. Muscle Strength

Muscle strength imbalance is a primary risk factor for knee injuries in marathon runners. Knee joint stability and movement control are maintained primarily by muscle groups including the quadriceps, hamstrings, iliotibial band (ITB), and gluteal muscles[13]. Current research on muscle strength imbalances in runners focuses mainly on two muscle groups: the quadriceps and the hip musculature[14]. Quadriceps weakness, particularly of the vastus medialis oblique (VMO), is a primary cause of patellar maltracking[15]. One study simulated muscle imbalance by modeling various knee extensor strength conditions without VMO activation and measured pressure distribution within the knee. The results indicated that quadriceps muscle imbalance, specifically VMO weakness, alters knee pressure distribution[16]. This is because the VMO is the primary active medial stabilizer of the patella, and its force is counteracted by lateral structures including the ITB, lateral retinaculum (LR), and vastus lateralis (VL)[17]. Weakness in the VMO creates an imbalance, leading to lateral patellar tracking and tilt, applying joint pressure to the lateral facet, potentially resulting in patellofemoral pain syndrome (PFPS)[18]. Furthermore, a longitudinal study by Finnoff et al. revealed an association between changes in hip muscle strength and sports injuries, showing that the injured group exhibited significant decreases in hip abduction strength ($P=0.002$) and external rotation strength ($P=0.01$) post-injury [19]. Souza et al. proposed that decreased eccentric strength of the hip abductors and external rotators can lead to relative femoral internal rotation and/or increased hip adduction moment, causing excessive lateral patellofemoral joint stress during dynamic activities like running, potentially leading to knee injury[20]. However, Rabelo et al. suggested that muscle weakness might be a consequence, rather than a cause, of knee injury[21]. Nonetheless, muscle weakness is consistently associated with the presence of knee injuries.

2.1.2. Running Technique

Running technique, including foot strike pattern, cadence, and stride length, is an important factor influencing knee health. Foot strike patterns during running are typically classified into three types: forefoot strike (FFS), rearfoot strike (RFS), and midfoot strike (MFS)[22]. FFS involves the forefoot contacting the ground before the heel, RFS occurs when the heel or rearfoot initially contacts the ground, and MFS is characterized by the forefoot and heel

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contacting the ground almost simultaneously[23]. RFS is the predominant foot strike pattern for both professional and amateur marathon runners. Biomechanical data from the 2017 IAAF World Championships (including 71 male and 78 female professional marathon runners) showed that at least 54% of male athletes and 67% of female athletes used RFS[24]. Another study of 936 amateur marathon runners found an even higher proportion of RFS (88.9%), followed by MFS (3.4%) and FFS (1.8%), with 5.9% exhibiting significant bilateral asymmetry[25]. Additionally, a study of a university cross-country team (n=52) found that 69.2% (36 runners) used RFS, while 30.8% (16 runners) used FFS. Although approximately 74% of runners experienced at least moderate annual injuries, the incidence of repetitive stress injuries in the RFS group was about twice that of the FFS group[26]. FFS runners land with the ankle in plantarflexion and greater hip and knee flexion, demonstrating lower impact peaks, average vertical loading rates, and instantaneous vertical loading rates, thereby enhancing shock absorption and reducing knee joint forces[27].

Although FFS results in lower peak knee load per step, the shorter contact time and higher cadence associated with FFS may lead to higher cumulative loads[27, 28]. Research suggests that while FFS shows significant differences in average ankle moment ratio and negative ankle power compared to RFS, differences in knee moment ratio and negative knee power are less pronounced, indicating that the ankle may be more susceptible to cumulative overload injuries in FFS running[22]. FFS is characterized by greater ankle involvement, manifested by higher ankle plantarflexor torque and increased force on the Achilles tendon. Due to enhanced energy absorption at the ankle joint during early stance, vertical impact peaks and loading rates are lower, resulting in lower peak contact forces and bending stresses at the knee[29, 30]. Therefore, while FFS may reduce the risk of knee injuries, it concurrently increases stress on the ankle. In contrast, RFS runners lack this ankle cushioning effect upon heel strike, transmitting greater axial force up the lower leg to the knee, thereby generating higher impact peaks and loading rates[31]. This implies RFS runners may be more susceptible to knee injuries.

Runner's knee injuries may be related to the magnitude of impact loading during the stance phase of running. Besides foot strike pattern, cadence and its associated stride length also influence impact loading[32]. One study showed that at +5% and +10% cadence conditions, runners exhibited smaller stride lengths ($p<0.01$), vertical center of mass displacement ($p<0.01$), braking impulse ($p<0.01$), and peak knee flexion angle ($p<0.01$), absorbing less mechanical energy at the knee ($p<0.01$). When cadence was reduced by 10%, stride length increased, and all joints showed significantly greater energy absorption ($p<0.01$)[33]. This indicates that as cadence decreases or stride length increases, the knee joint bears greater loads, thereby increasing the risk of knee injury.

2.1.3. Other Internal Risk Factors

Other internal risk factors include individual anatomical structure, history of previous injury, and sex. Research indicates that anatomical variations, such as genu varum (bow legs) or pes planus (flat feet), can lead to uneven force distribution across the knee, potentially causing injury with chronic accumulation[34]. A study by Desai et al. found that among 133 runners with a history of injury, 53 (40%) sustained a new injury during the study period, compared to 24% (22 out of 91) of runners with no injury history. Statistical analysis showed previous injury was significantly associated with a higher risk of new injury (HR=1.9, 95%CI: 1.2-3.2), meaning runners with a prior injury were 1.9 times more likely to sustain a new injury[35]. This association may be partly due to incomplete rehabilitation from the prior injury[36]. Furthermore, Mancino et al. demonstrated that female runners have approximately twice the incidence of knee injuries compared to males, a difference potentially linked to variations in frontal plane biomechanics. The team collected 3D kinematic and kinetic data from 32 high-mileage runners (16 males, 16 females) at speeds between 3-5 m/s, finding that females exhibited significantly greater hip adduction angles ($p<0.003$) and smaller knee adduction

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angles across all speeds, suggesting a potential link between this hip-knee coupling pattern and running-related knee injury rates. Further analysis indicated this sex-specific injury risk may stem from interactions between anatomical structure and biomechanical function[37]. Women typically have a wider pelvis, greater tibial torsion, and an increased Q-angle, often demonstrating smaller knee flexion angles, larger knee valgus angles, and altered muscle activation patterns during dynamic movements, contributing to knee instability[38]. Additionally, hormonal fluctuations, particularly involving estrogen and progesterone, are thought to influence the mechanical properties of ligaments. For example, estrogen has been shown to reduce collagen synthesis and increase ligament laxity, potentially compromising knee stability and increasing injury susceptibility[39]. These hormonal effects can be more pronounced during specific phases of the menstrual cycle, further elevating injury risk[40]. One study found significant increases in Anterior Cruciate Ligament (ACL) laxity during both the follicular (p=0.048) and luteal (p=0.006) phases, suggesting that hormonal surges of estrogen and progesterone may lead to greater ligament laxity, potentially increasing the risk of knee injuries in females during these phases[41].

2.2. External Risk Factors

2.2.1. Training Load

Training load typically refers to the stress placed on a runner during training, measurable through training volume (e.g., distance, duration) and intensity (e.g., pace, heart rate)[42]. Overuse running-related knee injuries are often considered a result of training errors. Some studies suggest that higher training volume may increase the risk of knee injury[43]. However, other research has found no association between training volume and injury risk, or even that high volume might have a protective effect on the knee[44,45]. This could be because only runners least prone to injury are able to prepare for high-volume marathons, while injury-prone runners may be forced to reduce their volume due to injuries[46].

Epidemiological and biomechanical research suggests links between specific injuries and training variables like volume and intensity. More precisely, sudden increases in running intensity are thought to be associated with injuries such as Achilles tendinopathy and plantar fasciitis, whereas sudden increases in running volume are linked to a higher risk of knee injuries like patellofemoral pain, iliotibial band friction syndrome, and patellar tendinopathy[47]. In marathon running, sudden increases in training volume play a key role in the development of knee injuries. It is widely accepted that an excessive sudden increase in running distance may overwhelm the adaptive capacity and tissue repair processes, ultimately leading to injury[48]. In a 14-week study involving 56 participants, runners who increased their weekly running distance by 20% to 60% had a significantly higher number of injuries after day 21 compared to those whose increase was less than 20% (RD, 22.6%; 95%CI: 0.9%, 44.3%; P=0.041)[49]. Another study indicated that novice runners increasing their running distance by more than 30% over two weeks appeared more susceptible to distance-related injuries than those increasing by less than 10%[50]. Regardless, this suggests that excessively large, sudden increases in training volume may elevate the risk of knee injuries in marathon runners.

The biomechanical mechanisms underlying injury development from sudden weekly distance increases remain unclear. However, some research suggests that running longer distances than usual may force runners to slow down, particularly when fatigued[51]. At the same distance, cumulative knee joint load is significantly higher when running at slow speeds compared to faster speeds. This provides a potential mechanistic basis for the association between increased running volume and knee injury risk[52,53]. Additionally, higher running frequency is often associated with greater injury risk. Among recreational and competitive runners, higher weekly running frequency may significantly increase the risk of knee injuries. One study further noted

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injury rates of 39% for runners running 5 days per week, 12% for 3 days per week, and 0% for 1 day per week[54].

2.2.2. Footwear Type

Running shoes consist of two main components: the upper and the sole. The sole, covering the plantar surface of the foot and interacting with the ground, is typically subdivided into the (1) outsole, (2) midsole, and (3) insole. Since many technological differences and variations between shoes occur in the midsole and insole, the impact of midsole construction and insoles on running biomechanics and injury risk has received significant attention[55]. Key characteristics of midsole construction include heel-to-toe drop and midsole hardness.

Minimalist running shoes are often hypothesized to have a protective effect against knee injuries during running. Compared to traditional shoes, minimalist shoes are characterized by lower mass, smaller heel-to-toe drop, and less cushioning[56]. It is hypothesized that minimalist shoes typically lead to higher cadence, a more forefoot strike pattern, and reduced peak flexion at the knee and hip during mid-stance, which may protect against injury[57]. However, in a 12-week training study preparing runners for a long-distance event involving 99 runners in the final analysis (23 injured), neutral shoes resulted in the fewest injuries (4 runners), while minimalist shoes resulted in the most (12 runners). The injury incidence was significantly higher for minimalist shoes throughout the 12-week period, suggesting greater risk associated with using minimalist shoes, particularly for longer distances[56].

Heel-to-toe drop also influences knee injury risk. Vertical loading rates and associated instantaneous peaks have been reported to increase as shoe drop decreases. In other words, low-drop shoes may reduce the cushioning properties of the shoe, potentially contributing to knee injuries[58].Furthermore, the relationship between heel drop and injury risk may be influenced by running frequency. Stratified analysis in one study showed that among occasional runners, those using low-drop shoes had a lower injury risk (HR, 0.48; 95%CI: 0.23, 0.98), whereas among frequent runners, those using low-drop shoes had a higher injury risk (HR, 1.67; 95%CI: 1.07, 2.62)[59]. However, because participants in that study were required to use the study shoes for all running, the transition from their usual shoes (approximately 78% of participants had not used low-drop shoes previously) to low-drop shoes may have contributed to the increased injury risk in frequent runners[60].

Research indicates that runners wearing shoes with harder midsoles have a higher injury risk (SWR, 1.52; 95%CI: 1.07, 2.16). Stratification by body weight revealed that lighter runners had a higher injury risk when using hard shoes (SWR, 1.80; 95%CI: 1.09, 2.98), while this was not the case for heavier runners (SWR, 1.23; 95%CI: 0.75, 2.03) [61]. A primary feature of modern shoes is their cushioning, designed to increase comfort and reduce impact forces upon ground contact. However, softer soles may increase the risk of excessive pronation, which could elevate injury risk for some runners[59]. Another study collected kinematic data from 16 asymptomatic runners and 17 runners with knee pain symptoms, both with and without insoles. Results showed that insoles reduced peak eversion by 3.68° (95%CI: 2.98, 4.38), peak eversion velocity by 53.28°/s (95%CI: 32.9, 73.4), and eversion range of motion by 1.33° (95%CI: 0.8, 1.9)[62]. While insoles may not alter transverse plane kinematics, they may alleviate knee symptoms by influencing other biomechanical variables[63].

3. Prevention Strategies for Knee Injuries in Marathon Runners

Corresponding preventive measures can be formulated targeting the modifiable risk factors for knee injuries in marathon runners. Preventive measures addressing modifiable internal risk factors primarily include balancing muscle strength and improving running technique. Measures addressing modifiable external risk factors primarily include training load management and selecting appropriate footwear.

3.1. Prevention Strategies Targeting Internal Risk Factors

3.1.1. Balancing Muscle Strength

Marathon runners can enhance knee stability and reduce injury risk by strengthening and stretching the surrounding musculature. Research suggests that strengthening the quadriceps, particularly the VMO, and the hip muscles is important for stabilizing the knee and preventing injuries. One study found that increased force from the VMO and other quadriceps reduced lateral patellofemoral pressure, suggesting improved VMO function decreases stress on the lateral patellofemoral joint cartilage[64]. However, an electromyography review concluded that it is nearly impossible to isolate VMO activation from the rest of the quadriceps, implying that effective isolation exercises for the VMO are difficult without external stimuli like electrical stimulation[65]. Nevertheless, squatting exercises with hip adduction can increase activity in both VMO and VL muscles, helping maintain balance between them[66]. Runners can also strengthen the quadriceps through exercises like squats and lunges[67].

Strengthening the hip muscles is widely regarded as an effective method for preventing knee injuries in athletes. Ferber et al. investigated changes in muscle strength, pain levels, and biomechanics in runners with PFPS following a 3-week hip muscle strengthening intervention. Post-intervention assessments showed: a significant 32.69% increase in isometric strength (P=0.04), indicating effective enhancement of hip abductor strength; a 43.10% decrease in Visual Analog Scale (VAS) pain scores (P=0.001); and significantly increased variability in knee motion during gait (P=0.01), reflecting improved motor control. These findings suggest that a targeted 3-week hip strengthening program can effectively increase muscle strength, alleviate pain, and enhance motor control in individuals with PFPS by improving lower limb biomechanics[68]. Exercises for strengthening hip muscles include banded walks and seated hip external rotation for hip external rotation, and bridges and standing hip extension for hip extension[69, 70].

3.1.2. Improving Running Technique

Proper running technique can reduce impact forces on the knee and lower injury risk. Currently, two main gait retraining techniques have emerged aimed at preventing knee injuries caused by excessive impact during running: (1) adopting a non-rearfoot strike (NRFS) pattern, and (2) increasing cadence or decreasing stride length[71]. Transitioning from RFS to FFS is commonly thought to reduce knee injuries in runners. A study by Cheung et al. showed that runners successfully transitioned from RFS to FFS through training, maintained this new pattern for 3 months post-program, and experienced reduced vertical impact peaks and loading rates, along with an 86% reduction in pain during activity and improvements in symptoms related to patellofemoral pain and functional limitations[72]. However, while FFS running may lower the risk of knee injuries like PFPS, it places greater stress on the ankle and calf, potentially increasing the likelihood of Achilles tendinopathy and plantar fasciitis[73]. Therefore, when runners transition from RFS to FFS, it should be done gradually and accompanied by strengthening exercises for the foot and calf to minimize injuries during the transition period[74].

However, Gamez et al. suggest that MFS may be the optimal foot strike technique for the marathon. Notably, FFS places higher demands on the foot muscles. Consequently, it appears less recommended for long-distance events like the marathon, especially for amateur runners[75]. Compared to RFS, MFS reduces vertical impact and lowers knee injury risk[76]. Compared to FFS, MFS avoids excessive ankle dorsiflexion, which can stress the calf and ankle[77]. Furthermore, MFS is associated with better performance and higher running economy[78]. Therefore, MFS is recommended for marathon runners, particularly amateurs.

Increasing cadence or decreasing stride length affects impact peaks, kinematics, and kinetics, and can thus be considered a potential mechanism for modulating injury risk in runners.

Specifically, at a constant speed, increasing cadence or decreasing stride length reduces vertical center of mass displacement, ground reaction forces (GRF), impact shock and its attenuation, and energy absorbed by the hip, knee, and ankle joints, thereby lowering injury risk[79]. In most cases, a minimum cadence change of 5% to 10% is required to observe biomechanical changes[80]. Cadence is influenced by various factors such as speed, body weight, technique, running distance, and runner's height. No single cadence value applies to all runners; it should be individualized based on each runner's specific needs[75].

3.2. Prevention Strategies Targeting External Risk Factors

3.2.1. Training Load Management

Training load management for marathon runners primarily involves controlling total training volume, weekly training increments, and running frequency. Participants training 40-50 km per week were 99.7% less likely to sustain a knee injury compared to those training 60-70 km per week (OR=0.003; 95%CI: 0.073; p≤0.0001). Correspondingly, subjects training 50-60 km per week were 94.7% less likely to experience a knee injury compared to those training 60-70 km per week (OR=0.053; 95%CI: 0.004, 0.728; p≤0.028)[81]. Begizew et al. recommend that weekly training distance be kept within 60 km to reduce knee injury risk in runners[81]. However, this value is not absolute; as a runner's fitness level improves, their tolerable training volume may also increase. Therefore, it is crucial to adjust weekly training distance dynamically based on individual capacity, especially for novice runners, who should start with lower weekly distances before considering increases.

Rasmussen et al. found that increasing weekly training volume might elevate a runner's relative injury threshold, potentially lowering knee injury risk[82]. Conversely, other studies have found that increasing weekly training volume elevates knee injury risk[83]. These conflicting findings may be due to not accounting for the magnitude of the weekly increase. Research indicates that more runners are injured when weekly running distance increases by 20% to 60%, whereas increases of less than 20% are not statistically associated with a significant injury probability[49]. Therefore, it is recommended that marathon runners limit weekly training volume increases to no more than 20%. It should also be noted that the cumulative load from week to week should be considered. For example, injury risk may be low with weekly increases of 5%, then 7%, then 3%. However, even if each individual increase is under 20%, injury risk may still be high when increases are 18%, followed by another 18%, and then another 18% within a 4-week period[49]. Additionally, an appropriate training frequency may lower knee injury risk. Nielsen et al. suggest an ideal training frequency of 2-5 sessions per week[84].

3.2.2. Selecting Appropriate Footwear

Marathon runners can mitigate injury risk by selecting appropriate footwear. Good running shoes can effectively reduce impact forces on the knee from hard surfaces and help distribute vertical load with each step. Research indicates that neutral shoes are associated with a lower injury risk compared to partial and full minimalist footwear. Therefore, caution is advised for marathon runners when using minimalist shoes during training and racing, particularly for long-distance sessions[56]. Heel-to-toe drop influences the cushioning properties of a shoe. Higher drop shoes offer greater cushioning, reducing vertical ground reaction forces (11-17%, p=0.009) and subsequently minimizing knee injury risk[58]. However, the cushioning effect of heel drop is also influenced by the runner's foot strike pattern. Therefore, marathon runners can select shoe drop based on their strike pattern. RFS runners are more likely to benefit from the enhanced cushioning of higher drop shoes compared to NRFS runners[85]. Furthermore, runners should transition gradually when changing between shoes with different heel drops. While one might assume experienced runners with well-adapted musculoskeletal systems could quickly adapt to different drops, a safe transition may actually require a longer period[60].

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Research results suggest that, concerning running injury risk, shoe cushioning is less critical for heavier runners, whereas lighter runners should tend towards softer shoes when choosing standard midsole footwear. However, the exact mechanism by which lighter runners using shoes with enhanced cushioning experience lower injury risk remains unclear[61]. Typically, motion control shoes are designed to correct foot pronation and are therefore recommended for runners with overpronation, potentially reducing knee risk associated with foot pronation. Cushioned shoes can facilitate pronation and are recommended for runners with supination. Neutral stability shoes are generally recommended for runners with neutral foot types[59].

Additionally, in one study, patients with PFPS were randomly assigned to an experimental group receiving 3 mm lateral wedge insoles or a control group receiving 6 mm medial wedge insoles. Both groups showed clinically meaningful pain reduction (>33%); however, no significant difference was found between the insole groups (p=0.697). To further explore the relationship between biomechanical parameters and outcomes, subjects were sub-grouped based on whether their knee adduction-abduction angle impulse (KAAI) increased or decreased. No significant difference in pain relief was found between these KAAI-change subgroups (p=0.146). However, when evaluating the absolute change in KAAI, a significant positive correlation was found between the absolute change in KAAI and the degree of pain relief after adjusting for baseline pain levels (R^2=0.21, p=0.030) [63]. These results indicate that both lateral and medial wedge insoles can effectively alleviate PFPS-related pain, but the differential efficacy may not be directly related to adaptive changes in knee dynamic loading (e.g., KAAI). Instead, an individual's response magnitude to the biomechanical intervention (i.e., absolute change in KAAI) may be an important predictor of pain relief. Another study on insoles suggested that custom-made insoles can protect runners' knees [86].

4. Recovery Strategies for Knee Injuries in Marathon Runners

A systematic rehabilitation protocol is crucial for managing knee injuries resulting from marathon running. The occurrence of knee injuries is primarily triggered by internal factors (e.g., muscle imbalance, poor technique) or external factors (e.g., overtraining, inappropriate footwear). Although the mechanisms of injury may differ depending on the causative factors, there are commonalities in tissue repair and functional restoration, making rehabilitation approaches generally consistent. Typically, the choice of rehabilitation protocol depends on injury severity. For mild knee injuries, non-surgical management, such as using supportive devices or immobilization with a cast to reduce joint load and promote tissue healing, is often sufficient. In contrast, more severe injuries (e.g., fractures, dislocations, or severe soft tissue damage) may require surgical intervention to restore joint stability and function [87]. Post-surgery, a series of systematic rehabilitation measures are necessary to facilitate functional recovery of the knee and help the runner safely return to regular training.

4.1. Rehabilitation Measures

The initial rehabilitation phase focuses on controlling inflammation using the PRICE principle: Protection, Rest, Ice, Compression, and Elevation[88]. Protection involves using devices to support injured tissues, limiting motion or providing cushioning. In the early recovery phase, custom orthoses may offer some benefits. For instance, considering a knee brace can further reduce load on the knee joint[89]. Cryotherapy is proven effective during the acute inflammatory phase and should be applied within the first few hours post-injury to limit the proliferation of secondary tissue damage[90]. Typically, the injured limb should be elevated at least 15 cm above heart level to facilitate venous and lymphatic drainage and prevent swelling[88].

In early rehabilitation, modalities like therapeutic ultrasound and electrical stimulation, along with medication, can be used to reduce inflammation and pain. Therapeutic ultrasound is often

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suggested for pain relief and to enhance the initial phase of muscle regeneration following muscle damage. Some evidence suggests low-intensity pulsed ultrasound can improve fresh fracture healing[91]. Electrical stimulation has been tried for fracture treatment, often for delayed unions and non-unions, with evidence tending to support its use for achieving bone healing[92]. Short-term use of non-steroidal anti-inflammatory drugs (NSAIDs) can provide pain relief and anti-inflammatory effects. However, some research suggests NSAIDs may prolong healing time[93].

Rehabilitation involves not only physical and pharmacological interventions but also crucial therapeutic exercise. This phase focuses on preventing knee stiffness, improving strength, and increasing range of motion and flexibility through exercise therapy. Patients can improve joint flexibility with static and dynamic stretching and enhance muscle strength through open kinetic chain (OKC) and closed kinetic chain (CKC) exercises[94]. When the knee has recovered sufficiently, low-impact cross-training can be introduced. Cross-training helps maintain overall fitness while placing minimal stress on the injured lower limb. Options include swimming, deep water running, and anti-gravity treadmill running[88]. Additionally, knee injuries can lead to mental stress, such as anxiety, depression, and mood disturbances, which can interfere with rehabilitation progress[95]. Therefore, addressing the athlete's mental stress is also important during recovery. Yoga, for example, has been shown to improve physical flexibility and balance while reducing anxiety and mental stress [96].

4.2. Return to Running

In the initial return-to-running phase, the runner primarily engages in low-intensity running, combining walking and jogging. Intermittent running helps gradually restore knee tolerance and reduce stress on cartilage[97]. In the intermediate return phase, the marathon runner can gradually increase the continuous duration of each run. For example, running speed should only be increased after achieving 20 minutes of continuous running, and intensity should not exceed moderate levels[88]. In the later return phase, normal running can resume. Once the knee adapts to moderate loads, running distance can be gradually increased, adhering to the 10% rule per week, and incorporating adequate rest days within the training schedule to allow full recovery. A progressive increase in training load effectively prevents recurrence of knee injuries and gradually builds the runner's endurance[50]. Furthermore, upon returning to running after a knee injury, marathon runners need to implement targeted prevention strategies based on the type of initial injury trigger (internal or external factors) to reduce the risk of re-injury. Regular testing and rehabilitation assessment are also necessary. Research indicates that wearable devices can monitor training load and track knee function recovery, helping to dynamically adjust the rehabilitation plan and ensure a scientifically sound return to running[98].

5. Conclusion

The popularity of marathon running has promoted the development of nationwide fitness but has also brought a high incidence of knee injuries. The occurrence of knee injuries is often closely linked to the combined effect of internal and external risk factors. Muscle strength imbalances and poor running technique are internal factors, while excessive training load and inappropriate footwear are external triggers. To prevent knee injuries, runners need to perform balanced training for the quadriceps and hamstrings, and adopt a non-rearfoot strike pattern and higher cadence during running to reduce knee stress. Additionally, scientific management of training load and selection of appropriate footwear can effectively protect the knee. For runners who have already sustained a knee injury, recovery strategies must follow scientific, gradual principles. In the initial phase, the PRICE principle, along with modalities like ultrasound, electrical stimulation, and medication, helps reduce inflammation and pain. In the

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rehabilitation training phase, strength and flexibility exercises help restore knee stability. In the return-to-running phase, progressively increasing training intensity and volume can effectively help runners safely return to the sport. Furthermore, regular monitoring of knee recovery using wearable devices can help timely adjust the rehabilitation strategy, ensuring a scientific return to running. Overall, this study provides marathon runners with systematic guidance from prevention to recovery, aiming to support healthy and safe marathon participation.

References

[1] Ding N, Su W L, Mu N, et al. 2023 China Road Race Blue Book [EB/OL]. (In Chinese). https://sdxw.iqilu.com/share/YS0yMS0xNTQ3MTYwNg.html

[2] FRANCIS P,WHATMAN C,SHEERIN K, et al. The proportion of lower limb running injuries by gender, anatomical location and specific pathology: a systematic view. J Sports Sci Med, 2019,18(1):21-31.

[3] Yang C, Wan X L, Feng R, et al. Influence of knee pain on knee joint biomechanics during the stance phase of running and landing jump in amateur runners with patellofemoral pain. China Sport Science and Technology, 2016, 35(06): 62-68.

[4] Ren S, Yin Y, Zhang S, et al. Gait analysis characteristics and guiding significance of runners after anterior cruciate ligament rupture. Science & Technology Review, 2016, 35(06): 43-48.

[5] Ren H J, Wei J B, Liu Y, et al. Application of MSCT combined with MRI in the diagnosis of knee joint injuries in marathon runners. Imaging Science and Photochemistry, 2016, 35(06): 971-975.

[6] Yu H X, Shen Y Y, Zhang Y J, et al. Application progress of quantitative MRI technology in knee cartilage of running populations. International Journal of Medical Radiology, 2016, 35(06): 588-593.

[7] Gao F. Research on prediction method of potential knee joint injury in marathon runners. Journal of Guangzhou Sport University, 2020, 40(01): 109-112+125.

[8] Chen Q H, Bi Q. Analysis of sports injuries and influencing factors in Hangzhou mountain marathon. Chinese Journal of Sports Medicine, 2016, 35(06): 557-560.

[9] Gao C M. Investigation on basic information, training characteristics and lower limb injuries of marathon enthusiasts [C]// China Sport Science Society. Proceedings of the 13th National Sports Science Congress -- Special Report (Sports Sociology Branch). Chengdu Sport University, 2023: 836-838.

[10] Hu H Y, Zheng Y L, Wang X Q, et al. Analysis of knee joint injury status and influencing factors in Shanghai International Marathon runners. Chinese Journal of Rehabilitation Medicine, 2016, 35(06): 297-302.

[11] Yang Y Z, Jiao W, Yuan S T. Investigation and analysis of running injuries and influencing factors in amateur marathon runners. Journal of Shandong Sport University, 2016, 35(06): 91-97.

[12] Zhou J, Zheng X Z, Ding J P, et al. MRI-based study on the correlation between thigh muscles, knee injuries and running factors in amateur marathon runners. Journal of Clinical Radiology, 2016, 35(06): 1956-1960.

[13] ABULHASAN J F, GREY M J. Anatomy and physiology of knee stability [J]. J Funct Morphol Kinesiol, 2017,2(4): 34.

[14] ELLINGER S, NEUROHR G A. Evidence-based treatment options for common knee injuries in runners [J]. Ann Transl Med, 2019,7(Suppl 7): S249.

[15] PETERSEN W, ELLERMANN A, GÖSELE-KOPPENBURG A, *et al*. Patellofemoral pain syndrome [J]. Knee Surg Sports Traumatol Arthrosc, 2014,22(10): 2264–2274.

[16] HAN S. Changes in patellofemoral joint mechanics in the presence of quadriceps muscle imbalance [D]. University of Calgary, Canada, 2020.

[17] COLLADO H, FREDERICSON M. Patellofemoral pain syndrome[J]. Clin Sports Med, 2010, 29(3): 379–398.

[18] ONSEN L T, KOH J L. Principles of prevention and rehabilitation for the patellofemoral joint[J]. The Patellofemoral Joint: A Case-Based Approach, 2022: 45–55.

[19] FINNOFF J T, HALL M M, KYLE K, et al. Hip strength and knee pain in high school runners: a prospective study [J]. PM&R, 2011, 3(9): 792–801.

[20] SOUZA R B, DRAPER C E, FREDERICSON M, et al. Femur rotation and patellofemoral joint kinematics: a weight-bearing magnetic resonance imaging analysis [J]. J Orthop Sports Phys Ther, 2010, 40(5): 277–285.

[21] DOS ANJOS RABELO N D, LUCARELLI P R G. Do hip muscle weakness and dynamic knee valgus matter for the clinical evaluation and decision-making process in patients with patellofemoral pain? [J]. Braz J Phys Ther, 2018, 22(2): 105–109.

[22] BURKE A, DILLON S, O'CONNOR S, *et al*. Risk factors for injuries in runners: a systematic review of foot strike technique and its classification at impact [J]. Orthop J Sports Med, 2021,9(9): 23259671211020283.

[23] GIANDOLINI M, POUPARD T, GIMENEZ P, *et al*. A simple field method to identify foot strike pattern during running [J]. J Biomech, 2014,47(7): 1588–1593.

[24] HANLEY B, BISSAS A, MERLINO S, *et al*. Most marathon runners at the 2017 IAAF World Championships were rearfoot strikers, and most did not change footstrike pattern [J]. Journal of Biomechanics, 2019,92: 54–60.

[25] LARSON P, HIGGINS E, KAMINSKI J. Foot strike patterns of recreational and sub-elite runners in a long-distance road race [J]. J Sports Sci, 2011,29: 1665–1673.

[26] DAOUD A I, GEISSLER G J, WANG F, *et al*. Foot strike and injury rates in endurance runners: a retrospective study [J]. Med Sci Sports Exerc, 2012,44(7): 1325–1334.

[27] RICE H M, JAMISON S T, DAVIS I S. Footwear matters: influence of footwear and foot strike on load rates during running [J]. Med Sci Sports Exerc, 2016,48(3): 10–15.

[28] YONG J R, SILDER A, DELP S L. Differences in muscle activity between natural forefoot and rearfoot strikers during running [J]. J Biomech, 2014,47(15): 3593–3597.

[29] KULMALA J-P, AVELA J, PASANEN K, *et al*.. Forefoot strikers exhibit lower running-induced knee loading than rearfoot strikers [J]. Med Sci Sports Exerc, 2013,45(12): 2306–2313.

[30] ROONEY B D, DERRICK T R. Joint contact loading in forefoot and rearfoot strike patterns during running [J]. J Biomech, 2013,46(13): 2201–2206.

[31] LANKHORST N E, BIERMA-ZEINSTRA S M, VAN MIDDLEKOOP M J. Risk factors for patellofemoral pain syndrome: a systematic review [J]. J Orthop Sports Phys Ther, 2012,42(2): 81–94.

[32] LIEBERMAN D E, WARRENER A G, WANG J, *et al*. Effects of stride frequency and foot position at landing on braking force, hip torque, impact peak force and the metabolic cost of running in humans [J]. Journal of Experimental Biology, 2015,218(21): 3406-3414.

[33] EIDERSCHEIT B C, CHUMANOV E S, MICHALSKI M P, *et al*. Effects of step rate manipulation on joint mechanics during running [J]. Med Sci Sports Exerc, 2011,43(2): 296–302.

[34] BENCA E, LISTABARTH S, FLOCK F K J, *et al*. Analysis of running-related injuries: the Vienna study [J]. J Clin Med, 2020,9(2): 438.

[35] DESAI P, JUNGMALM J, BÖRJESSON M, *et al*. Recreational runners with a history of injury are twice as likely to sustain a running-related injury as runners with no history of injury: a 1-year prospective cohort study [J]. J Orthop Sports Phys Ther, 2021,51(3): 144–150.

[36] SARAGIOTTO B, YAMATO T, HESPANHOL E, *et al*. What are the main risk factors for running-related injuries? [J]. Sports Med, 2014,44: 1153–1163.

[37] MANCINO F, GABR A, PLASTOW R, *et al*. Anterior Cruciate Ligament Injuries in Female Athletes: Is It Time for a New Approach? [J]. The Bone & Joint Journal, 2023,105(10): 1033-1037.

[38] BESSON T, MACCHI R, ROSSI J, *et al*. Sex differences in endurance running [J]. Sports Med, 2022,52(6): 1235–1257.

[39] HEWETT T E, FORD K R, HOOGENBOOM B J, *et al*. Understanding and preventing ACL injuries: current biomechanical and epidemiologic considerations - update 2010 [J]. N Am J Sports Phys Ther, 2010,5: 234–251.

[40] SMITH H C, VACEK P, JOHNSON R J, *et al*. Risk factors for anterior cruciate ligament injury: a review of the literature-part 2: hormonal, genetic, cognitive function, previous injury, and extrinsic risk factors [J]. Sports Health, 2012,4: 155–161.

[41] KHOWAILED I A, PETROFSKY J, LOHMAN E, *et al*. 17beta-estradiol induced effects on anterior cruciate ligament laxness and neuromuscular activation patterns in female runners [J]. J Womens Health (Larchmt), 2015,24(8): 670-680.

[42] HALSON S L. Monitoring training load to understand fatigue in athletes [J]. Sports Med, 2014,44(2): 139–147.

[43] VAN DER WORP M P, TEN HAAF D S, VAN CINGEL R, *et al*. Injuries in runners; a systematic review on risk factors and sex differences [J]. PLoS One, 2015,10(2): e0114937.

[44] KLUITENBERG B, VAN DER WORP H, HUISTEDE B M, *et al*. The NLstart2run study: training-related factors associated with running-related injuries in novice runners [J]. J Sci Med Sport, 2015,19(8): 642-646.

[45] DALLINGA J, VAN RIJN R, STUBBE J, *et al*.Injury incidence and risk factors: a cohort study of 706 8-km or 16-km recreational runners [J]. BMJ Open Sport Exerc Med, 2019,5(1): e000489.

[46] FOKKEMA T, VAN DAMME A A D N, *et al*. Training for a (half-)marathon: training volume and longest endurance run related to performance and running injuries [J]. Scand J Med Sci Sports, 2020,47(1): 33–38.

[47] NIELSEN R O, NOHR E A, RASMUSSEN S, *et al*. Classifying running-related injuries based upon etiology, with emphasis on volume and pace [J]. Int J Sports Phys Ther, 2013,8: 172–179.

[48] WARDEN S J, DAVIS I S, FREDERICSON M. Management and prevention of bone stress injuries in long-distance runners [J]. J Orthop Sports Phys Ther, 2014,44(10): 749–765.

[49] DAMSTED C, PARNER E T, SØRENSEN H, *et al*. The association between changes in weekly running distance and running-related injury: preparing for a half marathon [J]. J Orthop Sports Phys Ther, 2019,49(4): 230–238.

[50] NIELSEN R Ø, PARNER E T, NOHR E A, *et al*. Excessive progression in weekly running distance and risk of running-related injuries: an association which varies according to type of injury [J]. J Orthop Sports Phys Ther, 2014,44(10): 739–747.

[51] DORN T W, SCHACHE A G, PANDY M G. Muscular strategy shift in human running: dependence of running speed on hip and ankle muscle performance [J]. J Exp Biol, 2012,215: 1944–1956.

[52] PETERSEN J, SØRENSEN H, NIELSEN R Ø. Cumulative loads increase at the knee joint with slow-speed running compared to faster running: a biomechanical study [J]. J Orthop Sports Phys Ther, 2015,45: 316.

[53] PETERSEN J, NIELSEN R O, RASMUSSEN S, SØRENSEN H. Comparisons of increases in knee and ankle joint moments following an increase in running speed from 8 to 12 to 16 $km \cdot h^{-1}$ [J]. Clin Biomech, 2014,29: 959–964.

[54] FREDETTE A, ROY J S, PERREAULT K, *et al*. The association between running injuries and training parameters: a systematic review [J]. J Athl Train, 2022,57(7): 650–671.

[55] HOITZ F, MOHR M, ASMUSSEN M, LAM W-K, *et al*. The effects of systematically altered footwear features on biomechanics, injury, performance, and preference in runners of different skill level: a systematic review [J]. Footwear Sci, 2020,12: 193–215.

[56] RYAN M, ELASHI M, NEWSHAM-WEST, *et al*. Examining injury risk and pain perception in runners using minimalist footwear [J]. Br J Sports Med, 2014,48(16): 1257–1262.

[57] SQUADRONE R, RODANO R, HAMILL J, *et al*. Acute effect of different minimalist shoes on foot strike pattern and kinematics in rearfoot strikers during running [J]. J Sports Sci, 2015,33(11): 1196–1204.

[58] FU F, GUO L, TANG X, *et al*. Effect of the innovative running shoes with the special midsole structure on the female runners'lower limb biomechanics [J]. Front Bioeng Biotechnol, 2022,10: 866321.

[59] MALISOUX L, CHAMBON N, URHAUSEN A, *et al*. Influence of the heel-to-toe drop of standard cushioned running shoes on injury risk in leisure-time runners: a randomized controlled trial with 6-month follow-up [J]. Am J Sports Med, 2016,44(11): 2933–2940.

[60] RIXE J A, GALLO R A, SILVIS M L. The barefoot debate: can minimalist shoes reduce running-related injuries? [J]. Curr Sports Med Rep, 2012,11(3): 160–165.

[61] MALISOUX L, DELATTRE N, URHAUSEN A, *et al*. Shoe cushioning influences the running injury risk according to body mass: a randomized controlled trial involving 848 recreational runners [J]. Am J Sports Med, 2020,48(2): 473–480.

[62] RODRIGUES P, CHANG R, TENBROEK T, *et al*. Medially posted insoles consistently influence foot pronation in runners with and without anterior knee pain [J]. Gait Posture, 2013,37(4): 526–531.

[63] LEWINSON R T, WILEY J P, HUMBLE R N, *et al*. Altering knee abduction angular impulse using wedged insoles for treatment of patellofemoral pain in runners: a six-week randomized controlled trial [J]. PLoS One, 2015,10(7): e0134461.

[64] KHOSHKHOO M, KILLINGBACK A, ROBERTSON C J, *et al*. The effect of exercise on vastus medialis oblique muscle architecture: An ultrasound investigation [J]. Clin Anat, 2016,29(6): 752-758.

[65] BUCKTHORPE M, LA ROSA G, DELLA VILLA F. Restoring knee extensor strength after anterior cruciate ligament reconstruction: a clinical commentary [J]. Int J Sports Phys Ther, 2019,14(1): 159.

[66] CHANG W D, HUANG W S, LAI P T. Muscle activation of vastus medialis oblique and vastus lateralis in sling-based exercises in patients with patellofemoral pain syndrome: a cross-over study ［J］. Evid Based Complement Alternat Med, 2015(1): 740315.

[67] LEE J, LEE H, LEE W. Effect of weight-bearing therapeutic exercise on the Q-angle and muscle activity onset times of elite athletes with patellofemoral pain syndrome: A randomized controlled trial [J]. J Phys Ther Sci, 2014,26(7): 989-992.

[68] FERBER R, KENDALL K D, FARR L. Changes in knee biomechanics after a hip-abductor strengthening protocol for runners with patellofemoral pain syndrome [J]. J Athl Train, 2011,46(2): 142–149.

[69] CONTRERAS B M, CRONIN J B, SCHOENFELD B J, *et al*. Are all hip extension exercises created equal? [J]. Strength Cond J, 2013,35(2): 17–22.

[70] POHL P. The Patriot Program: a dynamic warm-up for the risk reduction of anterior cruciate ligament injuries in high school female basketball players [D]. Albany, NY: The Sage Colleges, 2013.

[71] FUTRELL E E, GROSS K D, REISMAN D, *et al*. Transition to forefoot strike reduces load rates more effectively than altered cadence [J]. J Sport Health Sci, 2020,9(4): 341–347.

[72] CHEUNG R T, DAVIS I S. Landing pattern modification to improve patellofemoral pain in runners: a case series [J]. J Orthop Sports Phys Ther, 2011,41(12): 914–919.

[73] ALMEIDA M O, DAVIS I S, LOPES A D. Biomechanical differences of foot-strike patterns during running: a systematic review with meta-analysis [J]. J Orthop Sports Phys Ther, 2015,45(12): 912–922.

[74] IRENE S. DAVIS, HANNAH M. RICE, SCOTT C. Why forefoot striking in minimal shoes might positively change the course of running injuries [J]. J Sport Health Sci, 2017, 6(2): 154-161.

[75] GAMEZ-PAYA J, ALADRO-GONZALVO A R, MARCOS D G, *et al*. Footstrike pattern and cadence of the marathon athletes at the Tokyo 2020 Olympic Games [J]. Appl Sci, 2023,13(11): 6620.

[76] BARNES A, GAMEZ-PAYA J, CASTELLI A, *et al*. Foot strike patterns in runners wearing floating heel, minimalist and conventional footwear [C]// Proc 33rd Int Conf Biomech Sports, Poitiers, France, 29 June–3 July 2015: 519–522.

[77] DAVIS I S, FUTRELL E. Gait retraining: Altering the fingerprint of gait [J]. Phys Med Rehabil Clin N Am, 2019,27: 339–355.

[78] FOLLAND J P, ALLEN S J, BLACK M, *et al*. Running technique is an important component of running economy and performance [J]. Med Sci Sports Exerc, 2017,49: 1412–1423.

[79] SCHUBERT A G, KEMPF J, HEIDERSCHEIT B C. Influence of stride frequency and length on running mechanics: a systematic review [J]. Sports Health, 2014,6(3): 265–274.

[80] HEIDERSCHEIT B C, CHUMANOV E S, MICHALSKI M P, *et al*. Effects of step rate manipulation on joint mechanics during running [J]. Med Sci Sports Exerc, 2011,43: 296–302.

[81] BEGIZEW D M, GRACE J M, VAN HEERDEN H J. Lower-extremity running-related injuries among 10,000-meter long distance runners in Ethiopia [J]. J Hum Sport Sci, 2018,14(2): 358–373.

[82] RASMUSSEN C H, NIELSEN R O, JUUL M S, *et al*. Weekly running volume and risk of running-related injuries among marathon runners [J]. Int J Sports Phys Ther, 2013,8(2): 111.

[83] KLUITENBERG B, VAN MIDDLEKOOP M, DIERCKS R, *et al*. What are the differences in injury proportions between different populations of runners? A systematic review and meta-analysis [J]. Sports Med, 2015,45: 1143-1161.

[84] NIELSEN R O, BUIST I, SØRENSEN H, *et al*. Training errors and running-related injuries: a systematic review [J]. Int J Sports Phys Ther, 2012,7(1): 58.

[85] MAI P, ROBERTZ L, ROBBIN J, *et al*. Towards functionally individualised designed footwear recommendation for overuse injury prevention: a scoping review [J]. BMC Sports Sci Med Rehabil, 2023,15(1): 152.

[86] SINCLAIR J, JANSSEN J, RICHARDS J D, *et al*. Effects of a 4-week intervention using semi-custom insoles on perceived pain and patellofemoral loading in targeted subgroups of recreational runners with patellofemoral pain [J]. Phys Ther Sport, 2018,34: 21–27.

[87] KRUTSCH W, MAYR H, MUSAHL V, *et al*. Injury and health risk management in sports [M], 2020,2nd Edition: 34–45.

[88] NICOLA T L, EL SHAMI A. Rehabilitation of running injuries [J]. Clin Sports Med, 2012,31(2): 351–372.

[89] HARRAST M A, COLONNO D. Stress fractures in runners [J]. Clin Sports Med, 2010,29(3): 399–416.

[90] KWIECIEŃ S Y, MCHUGH M P. The cold truth: The role of cryotherapy in the treatment of injury and recovery from exercise [J]. European Journal of Applied Physiology, 2021,121(8): 2125-2142.

[91] PALANISAMY P, ALAM M, LI S, *et al*. Low-intensity pulsed ultrasound stimulation for bone fractures healing: a review [J]. J Ultrasound Med, 2022,41(3): 547–563.

[92] GOLDSTEIN C, SPRAGUE S, PETRISOR B A, *et al*. Electrical stimulation for fracture healing: current evidence [J]. J Orthop Trauma, 2010,24(Suppl 1): S62–S65.

[93] KURMIS A P, KURMIS T P, O'BRIEN J X, *et al*. The effect of nonsteroidal anti-inflammatory drug administration on acute phase fracture-healing: A review [J]. The Journal of Bone & Joint Surgery, 2012,94(9): 815-823.

[94] VAN MELICK N, VAN CINGEL R E, BROOIJMANS F, *et al*. Evidence-based clinical practice update: practice guidelines for anterior cruciate ligament rehabilitation based on a systematic review and multidisciplinary consensus [J]. Br J Sports Med, 2016,50(24): 1506–1515.

[95] DALEY M M, GRIFFITH K, MILEWSKI M D, *et al*. The mental side of the injured athlete [J]. J Am Acad Orthop Surg, 2021,29: 499–506.

[96] UPADHYAY M K. Yoga in sports: a descriptive study [J]. Int J Yoga Physio Phys Educ, 2025,10(1): 4–5.

[97] MITHOEFER K, HAMBLY K, LOGERSTEDT D, *et al*. Current concepts for rehabilitation and return to sport after knee articular cartilage repair in the athlete [J]. J Orthop Sports Phys Ther, 2012,42(3): 254-273.

[98] WILLY R. Innovations and pitfalls in the use of wearable devices in the prevention and rehabilitation of running related injuries [J]. Phys Ther Sport, 2018,29: 26–33.